RENEWABLE ENERGY WASTE STREAMS

PREPARING FOR THE FUTURE

BRIEFING PAPER

Introduction

U.S. investment in renewable energy systems will create new kinds and new volumes of waste. Not only are there byproducts and energy demands associated with production of green technologies, but these systems also produce materials requiring careful end-of-life management to avoid creating new Superfund sites and wasting of scarce and valuable resources. The following paper provides a summary of the challenges the nation will face in the recycling and proper disposal of these wastes.

A renewable energy system can only be as green and sustainable as the manner in which wastes are minimized, repurposed, and/or disposed. In this summary, focuses on solar panels, electric vehicle battery systems, and windmills. These systems will be ubiquitous in the coming years and each presents significant challenges as the country considers how to manage its waste stream, or end-of-life cycle.

This briefing paper will touch upon the work that federal and state governments and the private sector has done and ongoing efforts that look ahead to addressing the challenges of renewable energy waste. EPA has already done work to promote recycling of renewable energy system materials. A considerable amount of research on renewable energy sources and the end-of-life issues associated with these sources has been conducted and sponsored by the Department of Energy (DOE) and in particular the Office of Energy Efficiency and Renewable Energy (EERE).[1] This paper summarizes some of the work done by DOE along with published information from other organizations on issues related to renewables' waste streams to highlight areas where further research and development are necessary.

It is vital that we adequately plan, prepare, and design renewable energy systems for reuse, recycling, and proper end-of-life material management in the present, or we risk creating new environmental and economic burdens in the future.

Overview

Solar Panels

Solar panels, also known as photovoltaic (PV) modules, present a looming expense to homeowners responsible for their removal and disposal at the end of their useful lives, as well as a potential environmental hazard. The toxic metals used in PV modules can leach into groundwater if the modules are disposed improperly. Consequently, some PV modules would have the potential to be considered a hazardous waste under the Resource Conservation and Recovery Act (RCRA) because they would fail the test for the toxicity characteristic when the PV modules are no longer in service. Currently, limited capacity exists to recycle today's solar panels. They likely will become less valuable to recycle as the

[1] This office "focus[es] on research activities, which industry does not have the technical capability to undertake, or which are too far from market realization to merit sufficient industry focus and critical mass." The 2018 and 2019 enacted R&D budget was $2.3 Billion (the 2020 request was $343 Million). Department of Energy FY -2020 Budget-in-Brief, page 14. https://www.energy.gov/sites/prod/files/2019/03/f60/doe-fy2020-budget-in-brief_0.pdf.

manufacture of solar panels becomes cheaper due to reduction in critical mineral usage. The possible designation of solar panels as RCRA hazardous waste further complicates and raises the cost of handling of panels. This raises the prospect of an increasing number of PV modules that won't be recycled at end-of-life. This in turn raises the risk that PV modules will be tossed into municipal landfills and mixed with other household trash or simply discarded by property owners or contractors in places with inadequate controls to restrict open dumping, reminiscent of the tire dumps of the past, many of which have ended up as Superfund sites on the National Priorities List.

Lithium-Ion Batteries

Lithium-ion batteries that no longer hold enough power for automotive use will pose a problem even before the coming wave of dead solar cells arrives. Lithium-based electric car batteries have caused fires[2] and typically contain toxic metals – both problems make recycling and/or disposal more complicated. The difficulty of separating the component materials from one another in an economical manner is a key obstacle to recycling these batteries. At present, manufacturers are taking some action so the burden does not directly fall on electric vehicle owners. Sponsored by certain automakers and battery producers, forms of adaptive reuse are underway, but they only slightly delay the inevitable: a time when the batteries no longer have value as a battery and require recycling or disposal. It is critical that these batteries are properly collected and managed to eliminate the risk of fires or leaching metals into the environment, creating future Superfund sites.

Windmills

Windmills largely present waste management challenges due to their size. The biggest difficulty in their storage and disposal is that they are large structures composed of large components and due to their mostly fiberglass composite construction, are of limited material reuse value. Shipping outdated models of windmills to lesser developed countries postpones but does not eliminate the need to appropriately manage components of windmills at the end of their useful lives. While the burden of management generally falls not on the landowner, but on the owner of the windmills, they may also pose a threat to groundwater if fluids and lubricants used by windmills leak or are dumped and contaminate land.

EPA's Role

There is a clear role for EPA to play as the U.S. prepares to recycle or dispose of these next-generation power sources. EPA has established a National Recycling Goal as an outgrowth of its leadership and convening of the broad spectrum of recycling stakeholders to organize them to work together to improve America's recycling system and work towards a more resilient materials economy. The America Recycles effort has focused on challenges such as the last-generation recycling infrastructure that has not kept pace with current generation of materials in the economy.[3] DOE possesses considerable expertise in the construction, design, installation, economics, and deployment of renewable energy systems. Moreover, DOE receives appropriations to conduct research, sponsor research, and offer prizes

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[2] Battery Fires Make Headlines as Electric Vehicle Sales Take Off, Insurance Journal, https://www.insurancejournal.com/news/national/2020/10/20/587257.htm (last visited 11/30/2020).

[3] EPA is limited in regulatory authority in the recycling arena. See prohibition on EPA from taking an official position on favoring one approach over another - Section 8003 of the Solid Waste Disposal Act, 42 USC Sec. 6983(g).

for innovation in this field. To solve these looming waste stream problems, EPA should partner with DOE to empower private industry and municipalities to manage the waste of the future.

SOLAR PANEL (PHOTOVOLTAIC OR PV) MODULES

Photovoltaic (PV) modules, or solar panels, will be a major contributor to renewable energy waste streams in the future, as decreasing manufacturing costs prompt increased proliferation. PV modules are becoming less expensive as new technologies in materials drive novel ways to convert sunlight into electricity. But PV modules don't last forever, and something will have to be done with them at their end of life.

PV modules are generally designed for a 30-year life but may last longer with a diminished power output, or may break or be replaced before then. The US is projected to have as much as 10 million tons of PV waste by 2050.[4] According to the Solar Energy Industries Association, in 2019 the US surpassed 2 million solar installations in the United States – just three years after surpassing 1 million. These installations are comprised of residential, commercial, and utility-scale solar installations.[5] Almost 50 percent of all installations are in California, but other regions of the country are also showing growth.

The growth of PV module use and thus PV module waste is already straining recycling and disposal capabilities.

> An empirical estimate of total US End of Life PV modules is unavailable, but recycled modules likely represent only a small fraction. Based on anecdotal reports, some modules are being disposed in municipal (non-hazardous) and hazardous landfills. Others are being stored until lower cost and easier recycling options develop, accumulated quantities become more economical to ship and recycle, and issues such as testing for hazardous waste determination (toxic contaminant leach testing)—which affect interstate transport and treatment options and costs—are resolved.[6]

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[4] Heath, G.A., Silverman, T.J., Kempe, M. et al. Research and development priorities for silicon photovoltaic module recycling to support a circular economy. Nat Energy 5, 502–510 (2020). https://doi.org/10.1038/s41560-020-0645-2 Pg 503

[5] https://www.seia.org/news/united-states-surpasses-2-million-solar-installations

[6] Heath, et al. pg 504

There is little to incentivize U.S. companies to recycle PV panels at present. Recycling processes for cadmium telluride and silicon PV modules have been developed, but, at least for U.S. recyclers, they cost more than the value of materials obtained. This situation poses an increased risk that PV modules will not be appropriately managed at the end of their useful lives and will cause future contamination issues if allowed to deteriorate under uncontrolled conditions. Many Superfund sites added to the National Priorities List shortly after the passage of CERCLA were sites where the operator of the site claimed and maybe even actually intended to recycle hazardous materials but was unable to do so. The owner accumulated large quantities of hazardous materials that were not properly managed and ultimately caused soil and groundwater contamination. It is foreseeable that the same kind of practices could occur with respect to PV panels in the absence of very effective programs for collecting and recycling PV panels available where PV panels are used.

Recycling PV currently costs $25 to $30 per module without factoring in the transportation costs to the recycler. "This figure is net of revenues currently gained by recyclers from recovered materials."[7] This cost will increase unless recycling infrastructure and technology improves as newer PV modules have found ways to use fewer valuable materials.

Precious metals are expensive components of solar panels that could potentially be reused when taken from old panels. Since 2016, the PV industry has consumed between 8.8 and 9.9 percent of the global silver supply annually.[8] The material value breakdown of a c-Si PV panel is approximately 47 percent silver (Ag), 26 percent aluminum (Al), 11 percent silicon (Si) , 8 percent copper (Cu), and 8 percent glass.[9] Recycling PVs and reutilizing these minerals can make sense economically, as mining for new minerals is expensive; however, as PV technology advances, less of these metals—silver in particular—is needed.

As the price of silver increases and the need for it decreases, businesses will have less economic incentive to recycle PV modules. Moreover, improvements to panels that make them less expensive also make them more fragile, and thus makes the reuse of module materials more difficult.

> [S]ilver use in solar cells has declined by 70% since 2010, and an expected continuing decline poses a challenge to recycling economics; copper is the likely lower-cost replacement. The trend toward thinner silicon wafers reduces the amount of silicon in each module, increases the probability of cell cracking, and reduces the probability of recovering intact cells.[10]

More homeowners are installing solar panels as they become cheaper, but those modules have less potential for recycling and recovery of materials due to smaller size and lower number of panels versus commercial installations.

In addition to silver, silicon components also pose a challenge to recycling PV modules. Unless there are breakthroughs in solar panel recycling research and development, the silicon recovered at end-of-life processing is not of the quality needed to make new PV cells; it is possible the recovered silicon could be used in other industrial applications, however. "If recycling processes can recover (or upgrade to)

[7] Heath, et al pg 504
[8] World Silver Survey 2020, The Silver Institute: https://www.silverinstitute.org/wp-content/uploads/2020/04/World-Silver-Survey-2020.pdf
[9] IRENA IEA-PVPS: End-of-Life Solar PV Panels 2016," p. 78: http://www.iea-pvps.org/index.php?id=9&eID=dam_frontend_push&docID=3123)
[10] Heath, et al pg 507

higher-purity silicon, the module recycling value could increase significantly. Virgin metallurgical-grade silicon costs approximately US$2 kg–1, whereas solar-grade silicon cost US$10 kg–1 or more."[11]

Internationally, some governments have begun developing module waste-management and recycling mandates or guidance to promote recovery of valuable materials (such as silver, copper, and aluminum) while mitigating hazard from toxic materials (such as lead or cadmium). However, not much has been done in the United States to address the PV waste issue; most of the novel policies driving, and often mandating, the recycling of PV modules originate in Europe.

Washington State is the first U.S. jurisdiction to require recycling at end-of-life. The 2017 law requires manufacturers selling in the state to submit a stewardship plan to the state's Department of Ecology that must include how they:

> . . . will finance the takeback and recycling system, and include an adequate funding mechanism to finance the costs of collection, management, and recycling of photovoltaic modules and residuals sold in or into the state by the manufacturer with a mechanism that ensures that photovoltaic modules can be delivered to takeback locations without cost to the last owner or holder.[12]

The law requires manufacturers to provide a takeback service for the manufacturer's (and predessors's) solar panels sold after July 1, 2017 at no cost to the owner of the solar panel. A product stewardship organization may act on behalf of a manufacturer or group of manufacturers. While this measure may protect homeowners from the likely unanticipated expenses and difficulty of disposing end-of-life PV modules, it does not change the solar waste management status quo and may discourage private industry's investment in developing PV technology further. Further as this law is so relatively new there is not any data about how effective this approach will be when the solar modules eligible for the takeback service will be taken out of service in the future.

<u>The California Approach</u>

California has sought to streamline recycling PV modules by reclassifying them as "universal waste" under the State's RCRA program, beginning Jan. 1, 2021[13]. Universal wastes are certain designated waste materials commonly generated by a wide variety of establishments and homeowners that are eligible to be handled under a streamlined set of hazardous waste standards. Universal wastes are allowed to be stored for longer than ordinary hazardous waste without a permit and do not need to be shipped with a hazardous waste manifest. Universal wastes are required to be managed in a way that prevents release to the environment and ultimately must be managed at a facility that meets RCRA's management standards.

California's decision to regulate PV modules as universal wastes comes in response to widespread failure by PV module generators (the person or entity that seek to dispose of or recycle the PV module) to comply with current state Department of Toxic Substances Control protocols for managing hazardous

[11] Heath, et al pg 506

[12] https://app.leg.wa.gov/RCW/default.aspx?cite=70.355.010

[13] Effective in January, 2020 EPA authorized changes California's implementation of RCRA to address aspects of California's universal waste rules. California's version of the universal waste rule, in a number of respects, is more stringent than the federal rule.

wastes.[14] Requirements for testing and control of hazardous waste significantly add to the expense and complexity of PV module disposal. PV modules may exhibit the hazardous waste characteristic of toxicity due to the presence of heavy metals such as cadmium, copper, lead, or selenium. If the waste is suspected to be hazardous, generators must determine the presence and quantity of toxic substances in the PV modules, which requires sampling and laboratory testing. The time and cost associated with this determination may discourage generators of waste PV modules from making these determinations. Particularly for homeowners, the complexity of RCRA and the potential cost of management poses a risk of the mismanagement of PV modules as managing hazardous waste is outside the experience and expectation of the average homeowner.

California's Department of Toxic Substance Control (DTSC) predicts that many PV modules will fail the federal and/or California state hazardous waste criteria for toxicity. PV modules that fail the federal hazardous waste criteria for toxicity are considered RCRA waste and are regulated as RCRA hazardous waste. Those that are not RCRA hazardous waste, but exhibit the California hazardous waste characteristic for toxicity, are non-RCRA hazardous waste. Under existing law, generators of hazardous waste PV modules are required to transport the waste to a permitted facility using a hazardous waste manifest and a registered hazardous waste transporter. This is a significant disincentive for generators of waste PV modules to test if the wastes are hazardous and transport hazardous wastes using an authorized transporter, due to associated time and costs, which prompt a significant motive to improperly manage and illegally dispose of them as municipal solid waste. Only time will tell if California is correct in this assessment that a universal waste classification will make transportation and storage of end-of-life PV modules easier and increase compliance with management regulations. The existence of universal waste regulations alone does not guarantee that eligible materials are universally managed by homeowners and others as universal waste. Further, such a classification does not solve any problems associated with the actual reuse or recycling of PV module waste materials, toxic or otherwise.

At present, then, while the production and use of PV modules continues to grow, recycling technology and processes for end-of-life units remain relatively stagnant. Without further research and development, market and legal incentives largely leave the U.S. facing the prospect of expired solar panels piled up in storage and waste facilities with the risk that unknowing or unscrupulous site operators will not implement appropriate protective measures for the panels under their control. This represents a potential environmental hazard, as PV modules can contain hazardous chemicals that, if improperly disposed of, may pollute soil and groundwater. Strategies like universal waste designation under RCRA may make some aspects of waste management easier in the short term, but such a designation alone does not establish an effective end-of-life management system. More work needs to be done to protect homeowners, in particular, who may not have even installed the PV modules they later become responsible for, from having to face unexpected expenses and regulatory burdens as their solar cells reach their end-of-life and require disposal or recycling.

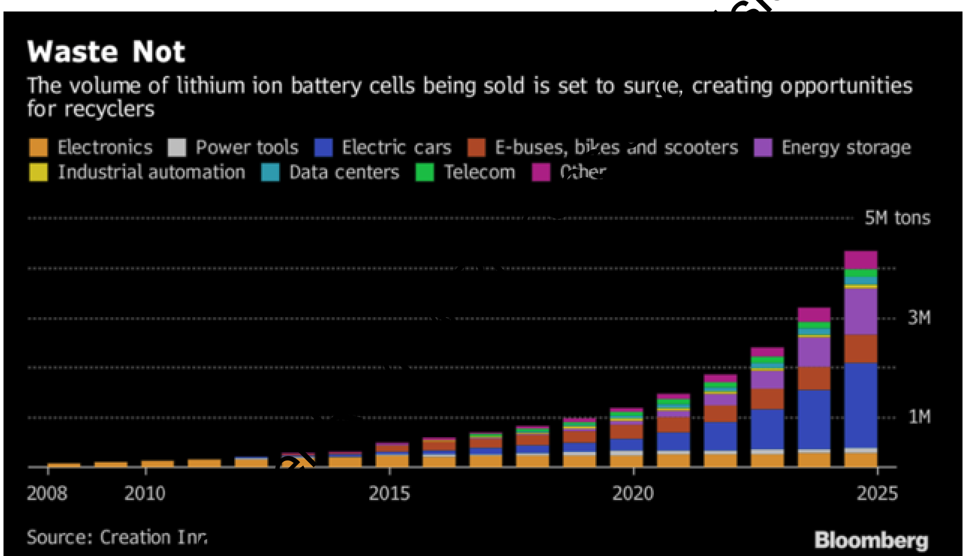
[14] Under RCRA homeowners can dispose of material and not be subject to RCRA regulation for the disposal of hazardous waste under the "household hazardous waste" exclusion. 40 CFR 261.4(b)(1). Yet the fact the homeowner is not subject to RCRA regulation does not prevent local municipalities from prohibiting certain kinds of waste materials from being sent to a municipal waste landfill. All states (e.g. California) have not adopted the federal household hazardous exclusion.

ELECTRIC VEHICLE BATTERIES

Like PV modules, electric vehicle batteries can be recycled currently, but the recycling process is made difficult by the complicated design and manufacturing techniques used to make them more efficient. Moreover, if not handled properly, the heavy metals contained in the battery can cause contamination of soil and water. If these batteries find their way into the municipal waste stream, they present risk of starting fires and other unexpected hazards and threats of contamination.

With present technology, it is expensive and often labor intensive to recycle lithium-ion (Li-ion) batteries. Sorting types of batteries and safely managing the batteries during collection is a significant part of that cost. Li-ion batteries have many different chemical compositions, with some more economically viable to recover than others. But they are not commonly labeled in any way that describes their chemistry, which makes extra care in sorting necessary.

The number of Li-ion batteries in the global marketplace is growing rapidly as consumer electronics, cordless and "smart" devices, and electric cars become more ubiquitous.



SOURCE: *Global lithium-ion battery cell sales, 2008 to 2025. Source: Bloomberg and Circular Energy Storage, 2018*

Batteries can be recycled through smelting, direct recovery, and other, newer processes, but all are expensive. The value of the raw minerals reclaimed from common battery recycling processes is only about a third of the cost of the recycling operation. At the present time the expense of extracting lithium from old batteries is five times more than that of mining for lithium.[15] Nevertheless, private industry continues to explore this space.

The following paragraphs provide as examples some reported efforts of different private entities to recycle or reuse used Li-ion automotive batteries. This information has been taken from readily available public reports and newspapers and has not been independently verified and none of the companies or processes referenced are in any way being endorsed by EPA. A U.S.-based startup,

[15] https://www.instituteforenergyresearch.org/renewable/the-afterlife-of-electric-vehicles-battery-recycling-and-repurposing/ (posted May 6, 2019)

Redwood Materials, claims it is pushing the reuse envelope, recycling old batteries from old phones and other personal electronics at the company's facility in Carson City, Nevada, as a source of the nickel, cobalt, and lithium needed for manufacturing new electric vehicle batteries.[16]

Reusing decommissioned car batteries offers another route to their disposal and productivity. Many electric vehicle batteries which are "spent" still have up to 70 percent of their capacity left–more than enough for other uses. After used electric vehicle batteries have been broken down, tested, and re-packaged, they can be used for things like home energy storage. Private companies like the UK-based startup Powervault and Australia-based Aceleron have created technologies that can turn batteries into home electricity storage units, electric bike batteries, and other tools. Old batteries can also be useful for storing solar energy and backing up traditional electrical grids. Powervault claims its technology can cut a household electricity bill by more than a third.[17]

Some manufacturers are using old batteries to provide new services. In Japan, Nissan repurposed batteries to power streetlights. In Paris, Renault has batteries backing up elevators, and GM is backing up its data center in Michigan with used Chevy Volt batteries. BMW AG, Toyota Motor Corp., BYD Co., and several renewable-energy storage suppliers are also among those trying to create an aftermarket for end-of-life electric vehicle batteries.[18] Most of these efforts at adaptive reuse, however, do not address the final disposal or complete recycling of these batteries, only delaying the time when battery materials that can cause fires or leach hazardous chemicals must be fully dealt with. Thus, the risk to the environment from these batteries remains as the distribution of these batteries become more widespread. While less common than in the past, one can still find in urban and rural areas environmental impacts from discarded automobile parts (e.g. tires) and indication of disposal of components (e.g. fluids and motor oil) in vacant lots and unprotected areas.

Since recycling Li-ion batteries still represents a considerable technical challenge, there is a risk that Li-ion batteries could cause environmental contamination if appropriate management of end-of-life Li-ion batteries is not effective, efficient, readily accessible, and widely available.

[16] Tim Higgins, *One of the Brains Behind Tesla May Have a New Way to Make Electric Cars Cheaper*, Wall St. J. (updated Aug. 29, 2020), https://www.wsj.com/articles/one-of-the-brains-behind-tesla-found-a-new-way-to-make-electric-cars-cheaper-11598673630.

[17] https://www.bloomberg.com/news/features/2018-06-27/where-3-million-electric-vehicle-batteries-will-go-when-they-retire

[18] Id.

WINDMILLS

Windmills are perhaps the least energy-producing and most physically difficult renewable waste stream to deal with. These behemoth power generators are not only laborious and expensive to transport and install, but they are burdensome to remove and recycle, too.

The larger the wind turbine, the larger the blade diameter, and the more power is generated; so turbine manufacturers and consumers are incentivized to create and install the largest windmills they can, not the turbines that can be disposed of most efficiently. The cost of transportation for an, often, 1,000-ton windmill, even piecemeal, is an enormous barrier to effective disposal. Aside from this difficulty, windmills have many mechanical components, each of which is comprised of any number of materials or elements; these components, including blades, are often made of composite materials, which make the process to separate and recycle them more complex.

The environmental impacts of decommissioning a site are akin to other large construction projects. Service roads or tracks may need to be laid (or roads made during installation may need to be upgraded) for cranes and trucks that will be used in dismantling and removal of the structures, including the removal of underground cables. There are chemical management concerns as well, as "[t]ransformers and some other components within wind turbines can contain oils and other lubricants."[19] More details on recycling windmill components is provided in the addendum to this paper.

The business relationship between windmill owners and the owners of the land on which windmills sit can be a further complication in ensuring proper recycling. In most leases, wind farm operators are responsible for returning the land to its previous state at the end of the wind farm's life. If the windmill owner goes out of business before the end of the lease then the landowners are left responsible for decommissioning and removal, and the landowner will need to hire a contractor with specialized expertise and equipment to safely disassemble and remove a windmill from their property – in some cases, this may mean the windmill is left in place to deteriorate.

Besides the sheer size of the windmills and the potential difficulty of delivering them to recycling stations, the largest problem with windmill disposal is that there are limited reuse or recycling options. A market for secondhand wind turbines exists, with growing demand in Eastern Europe, Asia, and Latin America; secondhand wind turbines allow developing nations to "establish their own wind energy industries and to profit from technology transfer with low capital expenditure."[20] But as a mere delaying tactic this puts the burden of responsible final disposal on countries less-prepared to shoulder the expense and technical challenge. The fiberglass and composite materials that make up the blades have little reuse value. In some cases, blades have been ground up and used as a substitute for aggregate for constructions, and in the Netherlands, windmill blades have been turned into playground equipment.[21] But without an established recycling process, it is clear there will be many more decommissioned windmill components mouldering in enormous piles than there are creative means and opportunity for repurposing them.

[19] Welstead, J., Hirst, R., Keogh, D., Robb G. and Bainsfair, R. 2013. Research and guidance on restoration and decommissioning of onshore wind farms. *Scottish Natural Heritage* Commissioned Report No. 591. (Pg 57).
[20] Welstead, et al pg 65
[21] https://inhabitat.com/wikado-playground-is-built-from-recycled-wind-turbine-blades-in-the-netherlands/

Until such a time as windmills can be efficiently dismantled so that component elements are separated out into units small enough to enter the existing waste stream and be reused or properly disposed of, each windfarm is a towering promise of future wreckage. Any lubrication oils and fluids associated with the windmill will need to be drained, collected and appropriately managed based on the composition of these materials. Mismanagement of these components can cause soil and groundwater pollution. With nowhere to go but wherever there is expansive available space, towers, turbines, and blades will sit stacked, waiting for this problem to be solved.

EPA'S ROLE IN RENEWABLE WASTE STREAMS

EPA can establish a goal for the recycling of renewable waste streams, engage with stakeholders on the issue as part of its America Recycles activities[22], and provide advice and expertise in material reuse and waste management. But to further improve U.S. renewable end-of-life processes, EPA should develop deeper partnerships with the Department of Energy to enable the research and development necessary to fill the gaps in current management technology.

DOE has the funds and offices already in place to provide research and expertise on the energy creation side—particularly the work done at the National Renewable Energy Laboratory (NREL). In PV technology alone, DOE's Solar Energy Technologies Office (SETO) has funded approximately $700,000 in past NREL projects on PV module life-cycle analysis and costs for module recycling.

In February 2019, DOE launched its lithium-ion battery recycling research and development initiative called the ReCell Center. ReCell's goals include: making battery recycling profitable by recovering high-value materials; designing processes to optimize yield, productivity, and cost; and, for increased national security, ensuring future supplies of critical materials for energy storage. The center has at least 50 researchers located in six laboratories and universities across the country.

DOE also has a $5.5 million Battery Recycling Program to reduce U.S. dependence on cobalt and lithium (two critical materials used in lithium-ion battery manufacturing) by reducing the amount of these materials needed for battery production and recycling the materials that are already in use.

DOE awarded $450,000 to NREL to analyze module end-of-life management and continue to coordinate the International Energy Agency Photovoltaic Power Systems Programme's (IEA-PVPS) PV sustainability efforts. Their approach includes investigating lessons learned from the IEA-PVPS program to help inform manufacturers and other stakeholders about current recycling requirements for PV hardware and efforts to design reusable modules and other equipment. Together with DOE's Advanced Manufacturing Office, SETO is funding a $200,000 project at NREL focused on both developing a certification for sustainable modules and designing recyclable modules.

DOE research and development can lead U.S. preparation for the management and recycling of renewable energy waste streams. New kinds and amounts of waste present a challenge, but with planning and smart investment they need not present new environmental hazards. Even as we manage the energy demands and byproducts of building these technologies, we must anticipate each unit's end-of-life, or else we will be simply passing off tomorrow's problem as today's solution. It is important to

[22] EPA's current America Recycles efforts are described and can be accessed on EPA's website. https://www.epa.gov/americarecycles

recognize that many promising reuse strategies simply delay the final question of how materials will be disposed of. This briefing paper is intended to provide a useful summary of some of the challenges to recycling PV modules, Li-ion batteries, and windmills, and to make clear the importance of anticipating gaps in sustainable waste stream management.

While consumers may purchase renewable energy or renewable energy-based products with good intentions, that does not prevent the unintended adverse environmental consequences of these products. The potential contamination from renewable energy waste streams can only be avoided if appropriate and effective preparations are in place and these renewable energy waste streams are properly managed. Renewable energy-based products are increasingly being installed and are and have been operating for some time. These products are ahead of the development and operation of the recycling and waste management systems designed to manage these products at the end of their useful lives in the most sustainable and environmental protective manner.

ADDENDUM ON WINDMILL WASTE

Below is a chart outlining the components of the wind turbine and other aspects of a windfarm outlining key decommissioning element, recycling options, relative costs and recommendations:[23]

Key Element	Constituents	Recycling Options	Relative cost of activity	Recommendations
Turbines	i. Blades Resin / Fibre Glass	Yes Off-site uses	Low-Medium	Remove off site. Potential to re-use.
	ii. Blade Hub and nose cone Cast Iron / Resin / Fibre Glass	Yes Off-site uses	Low-Medium	Remove off site. Potential to re-use.
	iii. Nacelle / Gear Box Iron / Steel / Copper / Resin / Silica	Yes Off-site uses	Low-Medium	Remove off site. Potential to re-use.
	iv. Tower Steel (sections)	Yes Off-site uses	Low-Medium	Remove off site. Potential to re-use.
Turbine Base	i. Backfill above and around base. Suitable engineering fill / crushed rock	Yes On-site uses e.g. backfill into void. Also can be used off-site	Low	If base needs trimmed or removed, use as backfill back into excavation. Use locally as fill. Export off site if viable.
	ii. Concrete Bases Concrete / steel reinforcement	Yes Limited options for on site uses. Options greater for off site uses.	High	Consider options to retain in situ. May need to trim top off base and then cap. All concrete and steel removed (as whole or partial demolition) to be taken off site. Processing could be done on site in a centralised location for onward disposal, or re-use if required.
	iii. Concrete Piles	Limited options other than breaking up and by others.	Medium	Cut back to a suitable depth and cap.
	ii. Concrete Base	Limited options other than breaking up and processing concrete/steel	Low-Medium	Break up and remove from site.
Crane Pad	i. Hardstanding Crushed rock / geogrid reinforcement Weathered and possibly vegetated	Yes On-site uses e.g. backfill into void. Also can be used off-site	Low-Medium	Retain, regrade, and then cover. Vital that original soils are managed to be re-used for restoration.
	ii. Soils In situ soils retained	Yes High potential if suitable for restoration. Low if unsuitable.	Low (if on site). Very High (if imported)	Have to use if possible, alternatively, use in less sensitive areas of site (e.g. as a subsoil)
Tracks	i. Forestry Spec Roads (granular fill) (also floating roads) Crushed rock / possibly geotextile separators / geogrids on weaker ground	Yes On-site uses e.g. backfill into void. Also can be used off-site Volumes could be significant and will be difficult to re-use all on site.	High (against leaving in situ and monitoring) if tracks to be removed. Significant volumes of material and high costs for reinstatement.	If suitable, can leave in situ. This may involve trimming (cut and fill) to suit profiles. If other risks are identified such as visual, hydrology etc, then tracks may be required to be removed. If to be fully reinstated make use of original topsoil and seed layer for reinstatement
	ii. Bituminous/ Asphaltic Roads	Yes Processed road planings	Low-Medium costs.	More likely limited to road junctions with public highway.

[23] Welstead, et al pg 62-64